DUAL-LINE DSL SYSTEM AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 60/257,275, entitled "Dual-Line ADSL Modem," filed December 21, 2000. This application is also related to U.S. Patent Application No. 09/791,970, entitled "Multi-Line ADSL Modulation," filed February 22, 2001. The subject matter of the related applications is hereby incorporated by reference. The related applications are commonly assigned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] This invention relates generally to digital subscriber line (DSL) systems and relates more particularly to a dual-line DSL system and method.

2. Description of the Background Art

[0003] Digital Subscriber Line (DSL) technology has existed for several years. There are some significant competing broadband technologies, such as cable and satellite television and wireless technologies such as mobile multipoint distribution services (MMDS) and local multipoint distribution services (LMDS). Some implementations of these competitive services may be better suited to video-on-demand services than current DSL technology, but not well suited to traditional data communications or interactive voice and

video applications. For these applications, DSL may have the advantages of greater upstream bandwidth and lower latency.

[0004] Hence, there is a need to improve DSL technology data rates so as to potentially deliver services such as video-on-demand in an effective manner. DSL service providers, therefore, generally need to increase the downstream data rate by about a factor of two to provide video-on-demand services to a large percentage of their customers. The service providers would prefer to increase the downstream data rate without running new copper wires from central offices to customer premises, which would likely be cost prohibitive.

[0005] The performance of a DSL system may be affected by several factors, including but not limited to, cable attenuation, Gaussian noise, near end cross talk, far end cross talk, impulse noise, and dispersion. Techniques for improving DSL data rates should address some of these limitations on DSL system performance.

SUMMARY OF THE INVENTION

[0006] The dual-line DSL system of the invention includes a central office and a customer premises coupled by two communication paths. In one embodiment, the communication paths are twisted-pair copper wires. The two communication paths provide a single high-bandwidth communication channel between the central office and the customer premises, which allows the central office to effectively transmit high-bandwidth signals such as video-on-demand to the customer premises without upgrading the existing loop plant.

[0007] In one embodiment, one data stream is inversely multiplexed at the asynchronous transfer mode (ATM) layer by a DSLAM at the central office to provide two signals. An ADSL transceiver unit-remote (ATU-R) at the customer premises receives the two signals and multiplexes them at the ATM layer to recreate the original data stream. The ATU-R of the invention is configured to reduce the effects of far end cross talk and near end cross talk on the signals received from the central office.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of one embodiment of an electronic network system;

FIG. 2 is a block diagram of one embodiment of an electronic network system, in accordance with the present invention;

FIG. 3 is a diagram illustrating far end cross talk and near end cross talk in an electronic network system, in accordance with the invention; and

FIG. 4 is a block diagram of one embodiment of the ADSL Transceiver Unit-Remote (ATU-R) of FIG. 2, in accordance with the invention.

DETAILED DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is a block diagram of one embodiment of an electronic network system 100 including a central office 102, a loop 106, and a customer premises 104. Central office 102 includes, but is not limited to, a Digital Subscriber Line Access Multiplexer (DSLAM) 103 that communicates via loop 106 with a splitter 130 attached to customer premises 104. Although splitter 130 is shown outside of customer premises 104, splitter 130 may alternatively be located inside customer premises 104. DSLAM 103 sends and receives DSL signals, such as ADSL signals, and Plain Old Telephone Service (POTS) signals via loop 106, which is embodied as a twisted-pair copper wire.

[0009] Customer premises 104 includes, but is not limited to, an ADSL Transceiver Unit-Remote (ATU-R) 132 (also sometimes called an ADSL modem), a personal computer (PC) 134, and a telephone 138. Splitter 130 splits the signals from loop 106, sending the DSL signals via path 140 to ATU-R 132 and the POTS signals via path 144 to telephone 138. ATU-R 132 processes the DSL signals and sends the resulting data, for example a web page or email message, to PC 134. Splitter 130 also receives signals from ATU-R 132 and telephone 138, and combines the signals for transmission over loop 106. DSLAM 103 includes an Asynchronous Transfer Mode (ATM) layer for processing data sent and received via DSL signals.

[0010] FIG. 2 is a block diagram of one embodiment of an electronic network system 200, in accordance with the invention. In system 200, central office 102 communicates with a customer premises 204 via two identical loops 206 and 208. Loop 206 and loop 208 communicate with separate ports of DSLAM 103 in central office 102. Loop 206 and loop 208 provide at least two communication channels between central office 102 and customer premises 204. Each loop 206, 208 is able to carry both DSL signals and POTS signals. Loop 206 and loop 208 allow central office 102 to deliver higher bandwidth data, for example video-on-demand, to customer premises 204.

[0011] Splitter 230 splits the signals on loop 206, sending DSL signals via path 242 to ATU-R 232 and POTS signals via path 236 to telephone 238. Splitter 230 also splits the signals on loop 208, sending DSL signals via path 240 to ATU-R 232 and POTS signals via path 246 to telephone 238. Although not shown in FIG. 2, other POTS devices such as facsimile machines and dial-up modems may send and receive signals via path 236 and path 246. ATU-R 232 processes DSL signals received via path 240 and 242 to produce data that is output to PC 234, and processes data received from PC 234 to produce DSL signals that are output to path 240 and path 242.

[0012] In one embodiment, loop 206 and loop 208 are viewed as a single dual-line channel. DSLAM 103 splits downstream DSL signals destined for customer premises 204 into two data streams at the signals' ATM layer. In another embodiment, loop 206 is a fast channel for real-time traffic that requires low latency and loop 208 is an interleaved channel for data that

requires lower error rates but can tolerate higher latency, such as streaming video. All other techniques for delivering data to customer premises 204 over two physical channels are within the scope of the invention.

[0013] ATU-R 232 is configured to recombine the two data streams at the ATM layer. In one embodiment, ATU-R 232 uses a multiplexer to recombine the two streams. The contents and functionality of ATU-R 232 are further discussed below in conjunction with FIG. 4.

[0014] The dual-line DSL system shown in FIG. 2 can achieve downstream data rates in excess of 10 Million bits per second (Mbps) for customer premises 204 up to about 12,000 feet from central office 102. The dual-line DSL system and method of the invention provide a competitive alternative to very high speed DSL (VDSL), which can provide data rates of about 13 Mbps but only at distances of about 4500 feet from a central office.

[0015] FIG. 3 is a diagram illustrating far end cross talk and near end cross talk in an electronic network system, in accordance with the invention. An ATU-R 310 sends and receives data via two lines, line 312 and line 314. Each of these lines is affected by far end cross talk (FEXT) and near end cross talk (NEXT). Far end cross talk occurs when signals in one line cross over to another line at the far end (from the point of view of ATU-R 310, the far end is typically a central office). In FIG. 3, FEXT 322 is when signals sent from the far end on line 312 cross over to line 314, and FEXT 324 is when signals sent from the far end on line 314 cross over to line 312. Near end cross talk occurs

when signals in one stream cross over to another stream at the near end (ATU-R 310). In FIG. 3, NEXT 326 is when signals transmitted by ATU-R 310 on line 312 cross over to line 314, and NEXT 328 is when signals transmitted by ATU-R 310 on line 314 cross over to line 312.

[0016] Wiring at a customer premises is typically not engineered to reduce cross-talk. This is particularly true when the customer premises is a home, where wiring may have been done ad-hoc without a well-planned topology. Also, the types of wire used in a customer premises may not be uniform. Cross-talk at a central office is typically not as severe due to the use of good engineering practices when designing the wiring topology.

[0017] The effect of FEXT and NEXT on each line can be represented as a transfer function. For example, through measurement and observation, a transfer function H1(f) representing the effects of FEXT 322 can be determined, and a transfer function H2(f) representing the effects of FEXT 324 can be determined. Transfer functions representing the effects of NEXT 326 and NEXT 328 can similarly be determined.

[0018] Since NEXT 326 and NEXT 328 stem from the same source (here ATU-R 310), the resulting NEXT interference can be cancelled by signal processing hardware of ATU-R 310 (not shown). FEXT 322 and FEXT 324 are being sent to ATU-R 310, so the signal processing hardware of ATU-R 310 can significantly reduce the effects of FEXT interference.

[0019] FIG. 4 is a block diagram of one embodiment of ATU-R 232 of FIG. 2, in accordance with the invention. ATU-R 232 includes, but is not limited to, Analog-to-Digital Converters (ADC) 410 and 412, adaptive filters 414, 416, 426, and 428, adders 418, 420, 422, and 424, and digital signal processor (DSP) 430. ATU-R 232 receives signals Xa(f) and Xb(f) from path 240 and 242, respectively. ADC 410 and ADC 412 convert these signals into digital signals. Adaptive filter 414 filters the output sample stream from ADC 410 by an adaptive filter transfer function C_{1F} that is approximately equal to the transfer function that represents the effects of FEXT from path 240 to path 242. Adaptive filter 416 filters the output sample stream from ADC 412 by an adaptive filter transfer function C_{2F} that is approximately equal to the transfer function that represents the effects of FEXT from path 242 to path 240. Adder 418 subtracts the output from adaptive filter 416 from the output of ADC 410, and adder 420 subtracts the output from adaptive filter 414 from the output of ADC 412, thus significantly reducing the effects of FEXT on the received signals.

[0020] Since the signals received by ATU-R 232 may be affected by signals transmitted by ATU-R 232, signals transmitted via path 240 (TXa) are also input to adaptive filter 428 and signals transmitted via path 242 (TXb) are also input to adaptive filter 426. Adaptive filter 426 filters the samples of TXb by an adaptive filter transfer function C_{2N} that is approximately equal to the transfer function that represents the effects of NEXT from path 242 to path 240. Adaptive filter 428 filters the samples of TXa by an adaptive filter transfer

function C_{1N} that is approximately equal to the transfer function that represent the effects of NEXT from path 240 to path 242. Adder 422 subtracts the output from adaptive filter 426 from the output of adder 418 and sends the sum to DSP 430, and adder 424 subtracts the output from adaptive filter 428 from the output of adder 420 and sends the sum to DSP 430, thus removing the effects of NEXT on the received signals.

[0021] Similar techniques may be used at central office 102 to reduce the effects of cross-talk at DSLAM 103, although the effects of cross-talk are typically not significant at central office 102.

[0022] The invention has been described above with reference to specific embodiments. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the appended claims. The foregoing description and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.